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SOLAR PARTICLE EVENTS DURING THE RISING PHASE OF SOLAR CYCLE 22*

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ABSTRACT

The solar energetic particle events since early 1989 have been among the most intense and hardest in almost three decades. These particles were measured by several Los Alamos instruments on satellites in geosynchronous orbit. Proton fluxes and spectral slopes as measured by the CPA instrument are reported for 1989 and 1990. The composition of heavy ($Z \approx$ 6–28) energetic ($\approx$2–50 MeV) ions as measured by the SOPA instrument is presented for the October 1989 event.

INTRODUCTION

Energetic particles associated with solar flares were discovered less than 50 years ago and have only been studied in any detail since the mid-1950s (Pomerantz and Duggal, 1974). Figure 1 summarizes proton fluences in solar-energetic-particle (SEP) events from 1954 until 1986 (Reedy, 1977; Goswami *et al.*, 1988). Other compilations (*e.g.*, Feynman *et al.*, 1990; Shea and Smart, 1990) often give different proton fluences for these events. Solar sunspot cycle 19 (1954–1964) had many large SEP events, while the next two solar cycles had events that were comparatively mild except for the August 1972 events. We are now entering only the fourth 11-year solar activity cycle for which SEPs have been quantitatively studied. Solar cycle 22, which started in October 1986 with the minimum in sunspots, had only a few small SEP events during its first two years, but since March 1989 there have been a number of very large SEP events. The smoothed sunspot number peaked in the middle of 1989 at about 160.

Events with large fluxes of solar energetic particles, especially those with many high-energy particles, affect many things in the near-Earth space environment (Gorney, 1990) and in deep space. For example, electronics can be upset (*e.g.*, Normand and Stapor, 1990) and/or degraded. The dose delivered by these particles can reach lethal levels ($\sim$1000 rem) in the matter of a few hours (Letaw *et al.*, 1987). Here results are presented on SEPs measured by two sets of Los Alamos instruments on a series of satellites in geosynchronous orbit. Additional measurements of particles during SEP events have been made by Los Alamos instruments on several NASA and DOD satellites, such as the Burst Detector Dosimeter on several satellites of the Global Positioning System at 4.1 R_E (Earth radii) and on other NASA and DOD satellites.

SOLAR PROTON FLUXES IN 1989 AND 1990

Since 1976, Los Alamos has flown a series of energetic-particle detectors at geosynchronous orbit at 6.6 R_E. The Charged Particle Analyzer (CPA) sensor systems measure protons and electrons over a range of energies. The CPA instruments are described in Baker *et al.* (1979). Energetic protons with energies from $\sim$0.4–160 MeV are measured

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by the HiP instrument subsystem, which uses three detectors in a telescope configuration to record protons in sixteen different energy intervals. The detectors are contained within an anticoincidence cup designed to veto signals produced by particles not coming through the collimator. Previous proton studies based on results from the CPA detectors mainly considered lower-energy protons trapped in the magnetosphere (*e.g.*, Baker *et al.*, 1979; Belian *et al.*, 1984). Up to now, only the SEP events since 1986 have been studied, but we hope soon to study events back to 1976. For several years prior to March 1989, the CPA instruments saw very little solar-particle activity. Since March 1989, many events with large fluxes of energetic solar protons have been observed. The daily averaged proton count rates above 9 and 60 MeV for years 1989 and 1990 are shown in Fig. 2.

We have studied the energetic protons during the SEP events in March, August, September, and October. Details of this study are in Reeves *et al.* (1991). For four 10-day periods, the counts in the HiP subsystem of the CPA on satellite 1987-097 for protons $\gtrsim$10 MeV were fit with a spectrum of the shape $dJ/dR = k \times \exp[-R/R_o]$ where J is flux and R is rigidity ($R = pc/q$) or relativistic momentum per unit charge. (An equivalent spectrum of the form $dJ/dR = k' \times \exp[\alpha R]$ was also used.) The proton fluxes and spectral slopes as a function of time during these four periods are shown in Fig. 3.

For these four periods and even within the period in October 1989, the protons often behaved differently. The March 6–15 period showed a very slow build up in intensity and the proton spectra were very soft (relatively few higher energy protons). The August 12–21 period showed a fast initial build-up and some structure in the decay phase of the event. The September 27 – October 6 period had a fast increase with a hard spectrum and an exponential decay phase. The October 18–27 period had four peaks. Three of these peaks had fast increases, exponential decays, and very hard spectra. The peak on October 20 was very sharp and intense but fairly soft. The times where both the fluxes were high and

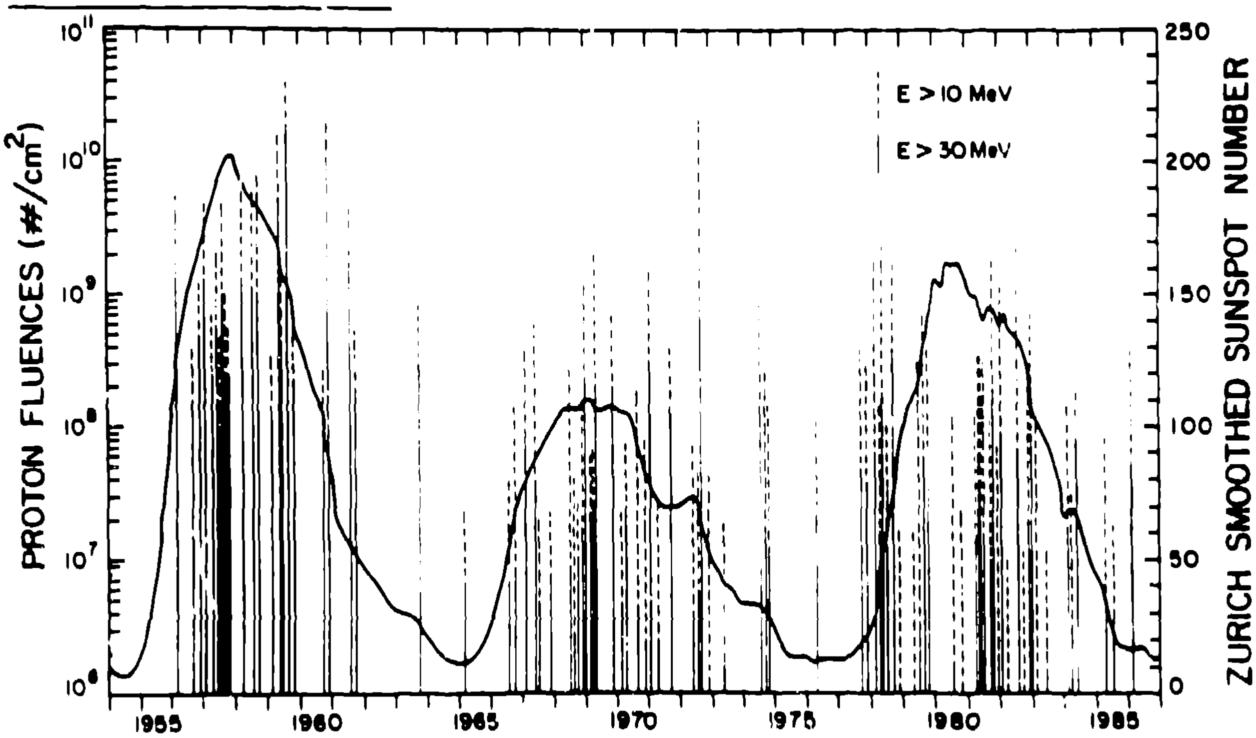

Fig. 1. Event-integrated proton fluences above 10 and 30 MeV and the smoothed monthly-averaged sunspot number for the last three solar cycles (numbers 19–21), from Reedy (1977) (up to 1973) and Goswami *et al.* (1988). Fluences for closely space events have been combined.

the spectral slopes were hard were those when ground level neutron enhancements were observed (Fig. 3). The fluences above 10 MeV in protons $(cm^2\ sr)^{-1}$ for these four 10-day periods were 5.9×10^7, 5.6×10^8, 6.8×10^8, and 2.2×10^9, respectively. The proton fluxes for these events correlated with other measurements, such as x-class solar flares, ground level neutron enhancements, trapped electron fluxes, and geomagnetic activity (Reeves *et al.*, 1991). Several large increases in proton fluxes appear to have been produced by shocks in interplanetary space, while others seem to have originated at the Sun.

HIGH-Z PARTICLES DURING OCTOBER 1989

Heavy ($Z \gtrsim 6$) energetic particles have been measured by the Synchronous Orbit Particle Analyzer (SOPA) instrument on satellite 1989-046. Details on the SOPA instrument and the results presented below are in Belian *et al.* (1991). The SOPA instrument consists of three nearly-identical detector telescopes arranged at different angles relative to the satellite's Earth-pointing spin axis. Each telescope consists of two silicon detectors: a very thin (4 μm) 10 mm^2 front detector and a thick (3 mm) 25 mm^2 back detector. The two detectors are completely surrounded by aluminum and copper shielding to stop 65-MeV protons and 6-MeV electrons except for an entrance collimator with baffles to minimize scattering. Particles that deposit more than 500 keV in the front detector, above the maximum energy deposited by protons, are considered to be heavy ions ($Z \geq 2$). Heavy

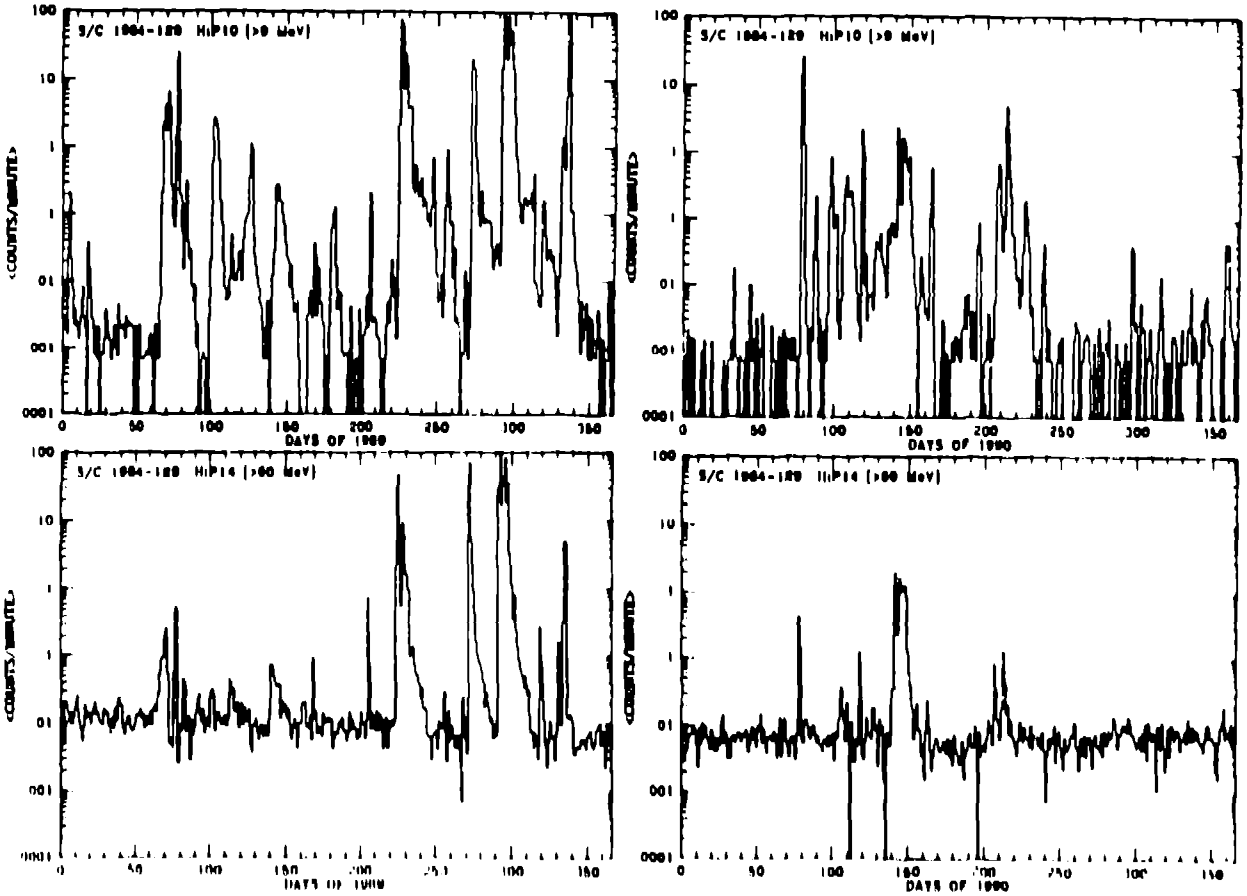

Fig. 2: Daily averaged count rates of protons with energies above 9 MeV for 1989 (top left) and 1990 (top right) and above 60 MeV for 1989 (bottom left) and 1990 (bottom right). The "background" counts are due to galactic cosmic rays.

ions are studied using a series of channels based on energies deposited in the front detector either with or without a coincidence pulse in the back detector and by two-dimensional maps from the pulse heights in both detectors.

Ions with energies from ~2 to 50 MeV from $Z = 6$ to $Z \approx 28$ have been identified in the October 1989 SEP event (Belian *et al.*, 1991). The composition of this event, normalized to oxygen, for the entire October 19–30 series of events was found to be higher than photospheric abundances and similar to the iron-rich events of McGuire *et al.* (1986) during 1974–1981. The relative abundances of Mg, S, Ca, and especially Ar were higher than those in the iron-rich events of McGuire *et al.* (1986).

The heavy ions observed during October 19–21 are shown in Fig. 4. The peak for heavy ions on day 293 (October 20) is wider than that for protons (Fig. 3). This peak was not associated with an X-ray flare. The greater width for the heavy-ion time history is probably due to the larger gyroradii of heavy ions than that for protons in a plasmoid moving with the solar wind (Belian *et al.*, 1991). The soft spectrum of protons in this peak (Fig. 3) also suggests that the energetic particles in this peak were accelerated by a shock-related process in interplanetary space (Reeves *et al.*, 1991).

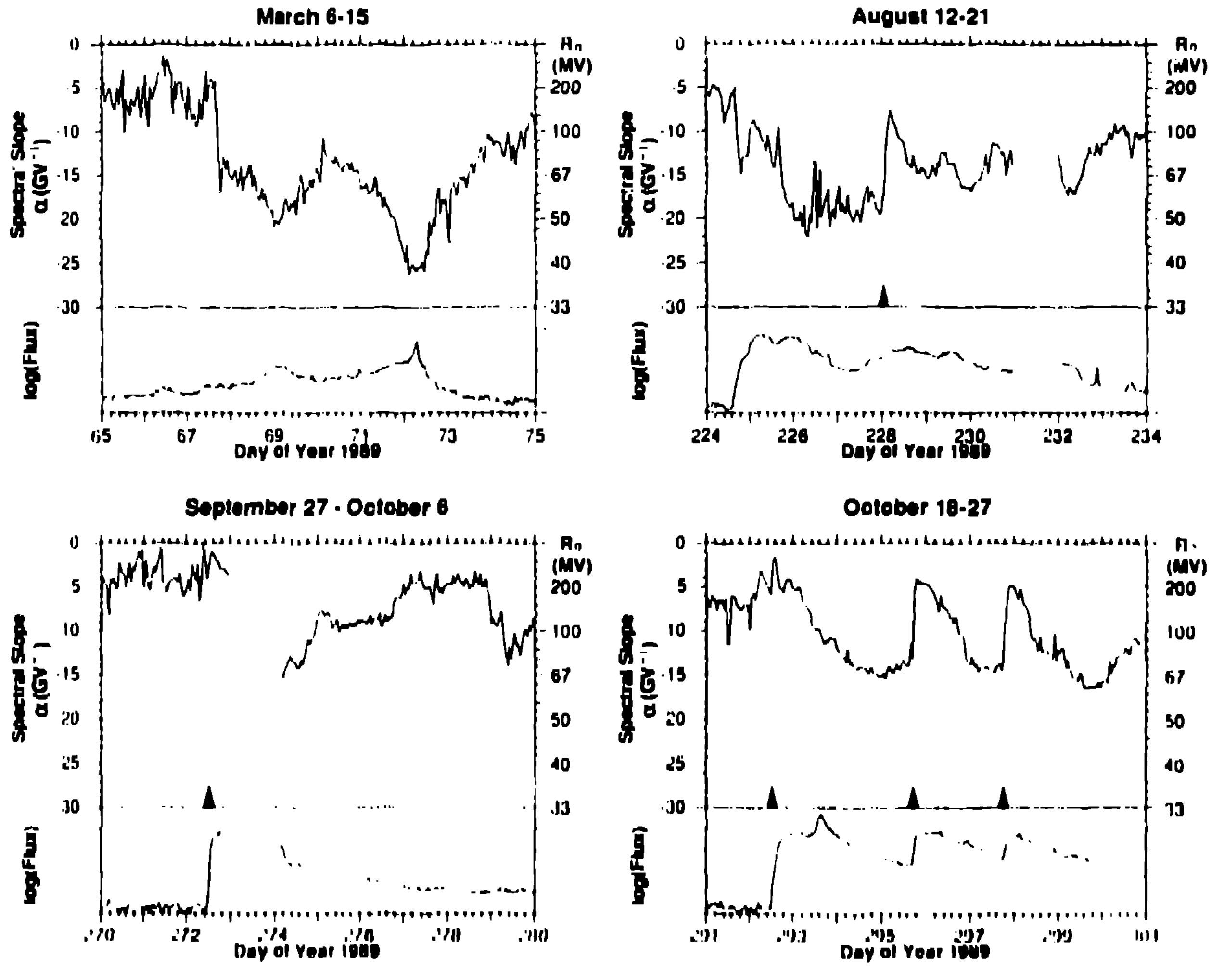

Fig. 3: The proton spectral slope (top panels) and fluxes (bottom panels) for four periods during 1989. The spectral slopes were determined by fitting the measurements with an exponential rigidity shape, exp[αR] or exp[-R/R_0]. Times of ground level neutron enhancements are indicated by upward pointing triangles.

REFERENCES

Baker, D. N., R. D. Belian, P. R. Higbie, and E. W. Hones, Jr. (1979), High-energy magnetospheric protons and their dependence on geomagnetic and interplanetary conditions. *J. Geophys. Res.* **84**, 7138–7154.

Belian, R. D., D. N. Baker, E. W. Hones, and P. R. Higbie (1984), High-energy proton drift echoes: Multiple peak structure. *J. Geophys. Res.* **89**, 9101–9106.

Belian, R. D., G. R. Gisler, T. Cayton, and R. Christensen (1991), High Z energetic particles at geosynchronous orbit during the great proton event of October, 1989. *J. Geophys. Res.*, submitted.

Feynman, Joan, T. F. Armstrong, L. Dao-Gibner, and S. Silverman (1990), New interplanetary proton fluence model. *J. Spacecraft & Rockets* **27**, 403–410.

Gorney, D. J. (1990), Solar cycle effects on the near-earth space environment. *Rev. Geophys.* **28**, 315–336.

Goswami, J.N., R. E. McGuire, R. C. Reedy, D. Lal, and R. Jha (1988), Solar flare protons and alpha particles during the last three solar cycles. *J. Geophys. Res.* **93**, 7195–7205.

Letaw, J. R., R. Silberberg, and C. H. Tsao (1987). Radiation hazards on space missions. *Nature* **330**, 709–710.

McGuire, R. E., T. T. von Rosenvinge, and F. B. McDonald (1986), The composition of solar energetic particles. *Astrophys. J.* **301**, 938-961.

Normand, E., and W. J. Stapor (1990), Variation in proton-induced upsets rates from large solar flares using an improved SEU model. *IEEE Trans. Nucl. Sci.* **37**, 1947–1952.

Pomerantz, M. A., and S. P. Duggal (1974), The sun and cosmic rays. *Rev. Geophys. Space Phys.* **12**, 343–361.

Reedy, R. C. (1977), Solar proton fluxes since 1956. In *Proceedings of the Eighth Lunar Science Conference* (New York: Pergamon Press), pp. 825–839.

Reeves, G. D., T. E. Cayton, S. P. Gary, and R. D. Belian (1991), The great solar energetic particle events of 1989. *J. Geophys. Res.*, submitted.

Shea, M. A., and D. F. Smart (1990), A summary of major solar proton events. *Solar Phys.* **127**, 297–320.

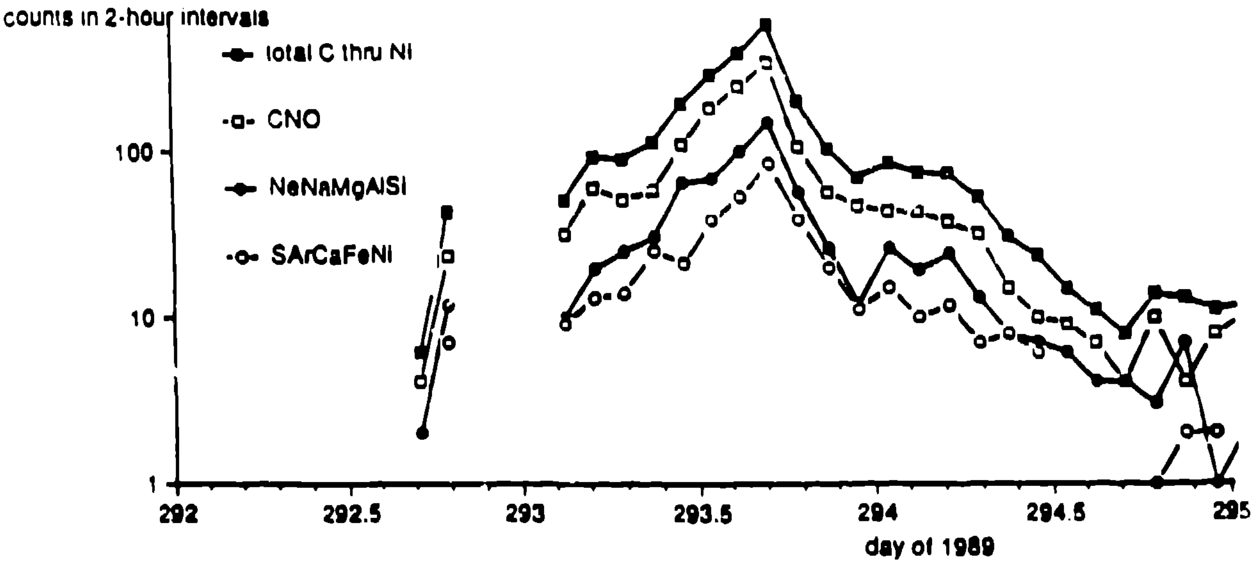

Fig. 4: The time history for several groups of heavy ions during October 19–21 shown as SOPA counts per 2-hour interval. See Fig. 3 for proton fluxes and slopes.